



Original Research Article

Effective Control of an alien invasive tree species (*Tabebuia pallida* [Lindl.] Miers) using chemical herbicides

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ABSTRACT

Forests in Mauritius are facing an alarming rate of encroachment by alien plant species which are changing the ecosystem function, equilibrium and composition of species and richness. Mauritius being a small tropical island is one of the recently colonized areas of the world where only a few descriptions of species composition and diversity exist. Invasive plant species are controlled by mechanical, chemical and biological methods. Efficient herbicide and suitable application methods were assessed for the control of *Tabebuia pallida* (Tecoma) in a forest area managed by the National Parks and Conservation Services (Mauritius). Effectiveness of herbicides to ringed barks showed Round-up (100 %) to be most effective compared to Triclon (73%) and Tordon 101 (40%). Drastic changes were observed with Roundup, irrespective of the application methods used. Significant differences were found among cut stump, ring barking and drilling application methods. Cut stump method was much more effective compared to the other two treatments. Ring barking also proved to be successful to some extent. Application of herbicides through drilling was ineffective. The use of herbicides was a significant factor in the death rate of the invasive species.

Introduction

Mauritius is a volcanic island and also the oldest Mascarene island occupying an area of 1865 km² (Saddul et al. 1995). Mauritius accounts for less than 2% of native forest where 50% are composed of native cover (Page and D'Argent, 1997). The forest harbours a high percentage of endemic species and has evolved unique biotas as they are geographically isolated and there is a lack of competitors and predators (Primack, 1998). According to Steinbauer et al. (2016), oceanic

islands are more prone to plant invasions. Much of Mauritius flora and fauna have disappeared during the last 400 years and only 5% of native forests remain whereby 1.6% is considered relatively good quality (NEAP, 1999).

There are many causes such as habitat destruction, habitat loss and increased spread of disease which has resulted in a decline in biodiversity and global species loss (Primack, 1995). Invasive species refers to plants and animals that have caused significant changes in the ecosystem (Richardson 1998). The native biodiversity is in danger from exotic plant species such as *Psidium cattleianum* and *Litsea glutinosa*, which are the worst invasive weeds in the native forest and hence reducing the growing number of native plants (Newfield et al. 2003). *Tecoma* was introduced in Mauritius in the year 1860 and is mainly known as a forestry tree. This tree is a characteristic species of tropical dry and moist forests in the native range. Where invasive, it establishes well in disturbed sites and forms dense thickets that shade out native plants and strongly reduce species richness. Regeneration of native shrubs and trees is prevented, hindering natural succession and forest regeneration (Weber, 2003). The tree forms mono-specific stands that provide very poor habitats for native flora and fauna and hence, there is little survival rate for vegetation or species regeneration (Kueffer and Mauremootoo, 2004).

This invasive species changes the ecosystem through habitat alteration, modifying nutrient regime, formation of monoculture and reducing native biodiversity. It spread and became invasive on some Pacific and Indian Ocean islands in 1999, notably in Hawaii, the Marshall Islands, and the Chagos Archipelago (PIER, 2008). *T. pallida* was also recorded as invasive in Mauritius (Parnell et al. 1989) and in the Seychelles (PIER, 2008). Competitiveness and vitality of weeds, financial status, availability of equipment, size of infestation and habitat are some of the factors essential to develop proper control methods. Eradication of the weeds is more desirable if the weed invasion is over a limited area and the weed itself is not common. The practice and costs for eradication is much higher than for control methods. Mechanical control is a very common method of controlling invasive alien species. Some examples of mechanical control are hand pulling, tillage, hand hoeing, flooding and heat. Kueffer and Mauremootoo (2004), found that about 315-890 person-hours per ha were required during the initial weeding of upland conservation management area plots but up to 2000 person-hours per ha were necessary while weeding the lowland forest of Ile aux Aigrettes (Mauritius). Labor cost was estimated to be about 90000 MRU (US\$ 2500) per ha and the maintenance cost may come up to about 4200 MRU (US\$ 117) per ha. Herbicides are effective and act relatively fast upon targeted weeds and can reduce the re-sprouting or reappearance of weeds

(Brooks, 2004). Applied together with mechanical control methods, herbicides increase effectiveness (Mungroo, 1996; Mungroo and Tezoo, 1999).

Herbicides can be applied to prevent sprouting of cut stumps, or to kill seedlings after felling or burning. Herbicides can target, for example, grasses or broad-leaved species, leaving other plants unharmed. However, there are legitimate concerns over the use of herbicides in terms of potential environmental impacts (Mehdizadeh et al. 2017). In North America, herbicide technology has constantly been evolving with forest management over the past 6 decades and its use has become important for modern forestry practice. The use of chemical control is often governed by legislation, and the effective and safe use of herbicides requires a relatively high level of training; both of these factors can restrict the use of chemical control on a large scale (Wilgen et al. 2001). Use of herbicide has been increasing in forest management for control of non-native invasive plants, especially on national forest lands of United States (Miller, 2003; Shepard et al. 2004). Several studies have been carried out on the native forest and its degradation in Mauritius but the main problem in these studies of biodiversity of Mauritius is a lack of biological data on the forest ecosystem (NPCS, 2006). At present few information have been published on control of invasive alien species using herbicide in the native forest of Mauritius. Thus, carrying out a full inventory of Tecoma (*Tabebuia pallida*) and its management in the Black River Gorges National Park (BRGNP) will help to formulate a strategy to manage this weed and conserve sustainably all the rare species. The objective of this project was to assess the efficiency of different herbicides and application methods for the control of Tecoma.

Materials and Methods

The study site was located in the Black River Gorges National Park (BRGNP), situated in the south west part of Mauritius. The Black River Gorge National Park stretches at from latitudes 20° 21'S to 20° 29' S and longitudes 57° 22' E to 57° 31' E. The BRGNP has diverse forest vegetation which constitutes mainly of tropical coastal forests and extending to high altitudes forests. The altitude of the Black River range is about 100-800m above sea level. The range comprises of the lower gorges and its surrounding cliffs together with forested area around the northern part of the Chamarel village. Threatened endemic bird and rarest endemic plants have adapted to stay at the BRGNP. The BRGNP covers 6,574 ha of state land and was officially proclaimed in 1994 (NPCS, 2006). The park is one of the most successful and cost-effective programs in focus to save all the threatened birds like the Mauritius Kestrel (*Falco punctacus*) and Pink Pigeon (*Columba mayeri*). There is a visitor's center, an information desk and four field research stations that are present in the National Park. Population counts as density of *T. pallida* were carried within 20 quadrats of 5

m². Adults and seedlings were counted to determine regenerative capacity of *Tecoma*, and other exotic, indigenous and endemic species were also monitored within quadrats to assess invasiveness. Herbicides were applied in the month of November and December. Period of investigation was in full summer from November to January. These months are considered to be the driest months for the region Black River and thus, the most appropriate time for the investigation. Observations were made every three weeks and three monitoring periods were obtained. The gradual effects of the herbicides on this species were recorded as yellowing of leaves, leaf fall, new sprouts from cut stumps. Application methods were: 1) ring barking/girdling 2) cut stumps and 3) Drilling (Table 1). Chemical herbicides used were: 1) round-up 2) Tordon 101 and 3) Triclon (Table 2). For cost-benefit analysis, Mauritian rupees (Rs/MUR) were converted to US \$ at present rate of 1US\$=Rs 36.

Table 1. Equipment used for the three different herbicide application methods.

No.	Application method	Equipment
1	Ring barking or Girdling	Machete or short axe or chisel and hammer, 2 inch paint brush, open container, gloves, safety glasses
2	Cut stump	Machete, chainsaw, protective wear (Gloves, safety glasses, boots, hard hat, face shield), fuel, chainsaw oil, round metal file, 2 inch paint brush, open container.
3	Drilling	Rechargeable drill + wood drill bit or flat chisel + hammer or short axe, 50ml syringe, gloves, safety glasses

Table 2. Volume and mixtures of herbicide used.

Herbicide	Application method	Vol. of herbicide (ml)	Vol. of water (ml)	Vol. of mixture (ml)
Tordon 101	Ring bark	100	20	120
	Cut stump			
	Drill			
Triclon	Ring bark	100	20	120
	Cut stump			
	Drill			
Roundup	Ring bark	100	20	120
	Cut stump			
	Drill			

Results and Discussion

Observations showed that *Tecoma* trees and their seedlings had a very high density and had a great invasive capacity leaving fewer chances for other species to regenerate (Figure 1 and 2). *T.pallida* outnumbered the indigenous species.

Cut stumps application method yielded 100 % mortality ($n=55$, re-sprout=nil) irrespective of herbicide used and there were no side buds sprouting from the stumps. Ring barking (Table 3 and Figure 3) was efficient as there were major changes observed in the structure of the trees. During the first and second monitoring of the technique, the plants treated showed no repair mechanisms to cover the removed parts of the bark that were wounded. Plants that were treated with herbicides showed signs of poisoning like discoloration and deformed leaves ($n=30$). Poisoning were observed as speeding up, ceasure or changes in the plants' normal growth patterns, evident as drying out of leaves or stems and complete defoliation. Complete death of the tree may be classified as all the leaves of the tree have dropped and there are weak branches and there are subsequent bud developed.

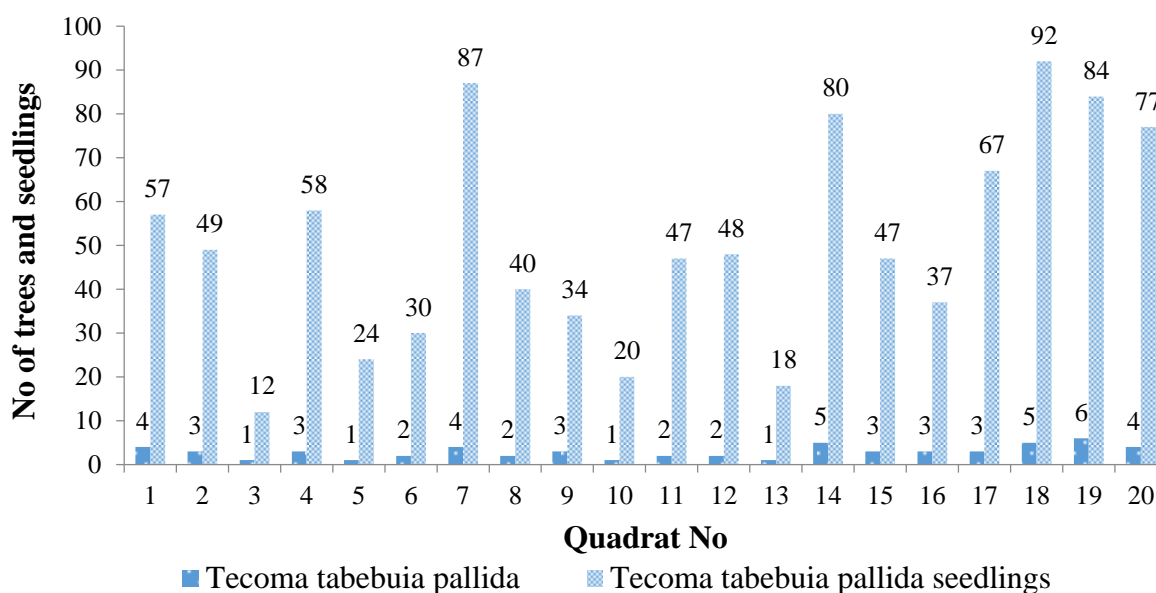


Figure 1. Number of *T. pallida* adults and seedlings per quadrat (5m²).

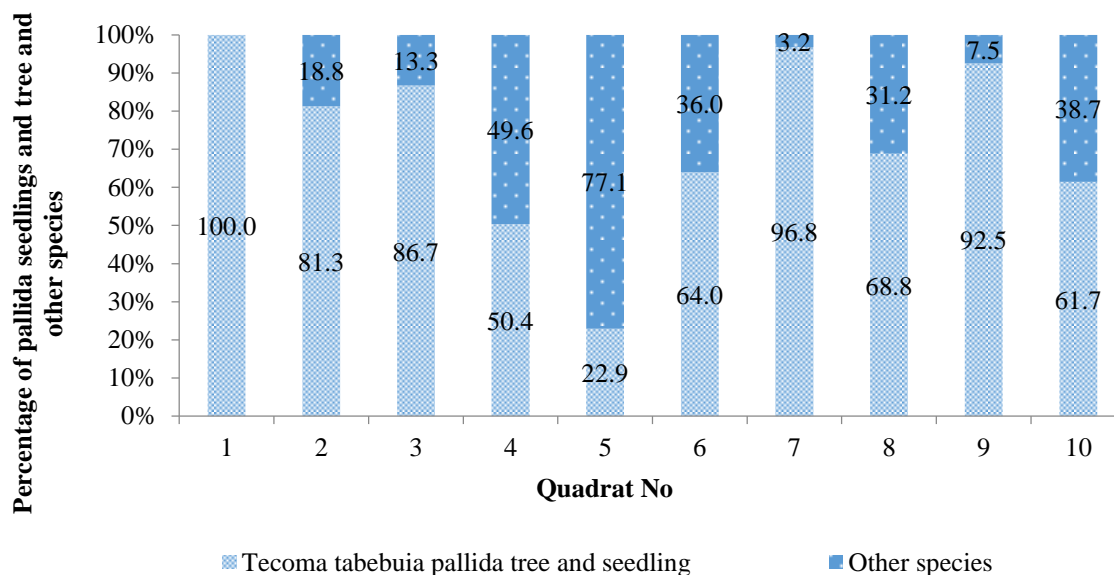


Figure 2. Number of *T. pallida* individuals compared to any other plant species per quadrat (5m²).

Table 3. Efficiency of ring bark application method on *Tabebuia pallida*.

Treatment		Number (n=15, for each treatment)	Percentage (%)
Ring bark	Apparently healthy	15	100
	Poisoning	-	-
	Dead	-	-
Ring bark + Roundup	Apparently healthy	-	-
	Poisoning	15	100
	Dead	-	-
Ring bark + Tordon 101	Apparently healthy	5	33.3
	Poisoning	10	66.7
	Dead	0	0
Ring bark + Triclon	Apparently healthy	9	60
	Poisoning	6	40
	Dead	0	0

During the third monitoring period it was found that all the leaves had fallen off. Ring barking with roundup herbicide proved to be 100% efficient. Out of 15 trees that were treated 5 were poisoned and 10 were completely dead. For Tordon 101 even after 9 weeks of monitoring 4 trees were found to be healthy, 10 were poisoned and only 1 completely dead. Mortality rate was hardly satisfactory meaning that Tordon 101 worked fairly well with this method. Ring barking with Tordon herbicide was 73.3% efficient. Triclon application was not that effective compared to the

other two herbicides. The lower leaves of the trees were turning yellow showing a sign of discoloration. Nine trees were apparently healthy and 6 trees were poisoned.

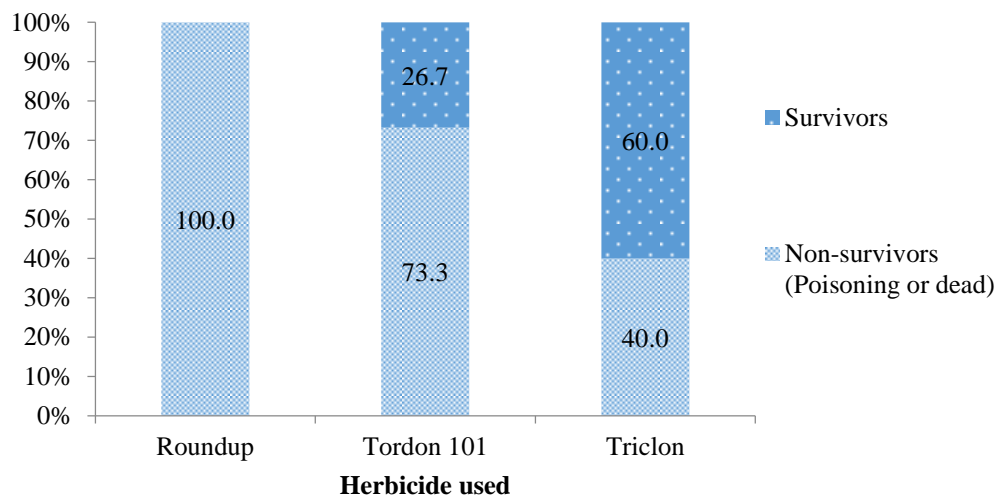


Figure 3. Percentage of survivors to non-survivors of ring barking.

The drill technique did not produce desired results. The mortality rate was low compared to cut stump and ring bark techniques. There was relatively low sign of poisoning for the 30 plants that were treated (Table 4 and Figure 4). Application of roundup resulted in drying up of the leaves that were at a lower part of trees. Even after the third monitoring, no major changes were observed. The leaves on trees were still green and branches solid as before which showed that the application was not very effective. 80% of plants survived from triclon application, which means that the herbicide is either ineffective or the volume used is low or they have not reached the cambium layers of the plants. The average time taken by a person to weed one quadrat of 7m² varied among the different techniques.

Table 4. Response of *T.Pallida* to drill technique with the respective herbicides used.

Treatment		Number	Percentage (%)
Drill	Apparently healthy	10	100
	Poisoning	-	-
Drill + Roundup	Apparently healthy	5	50
	Poisoning	5	50
Drill + Tordon 101	Apparently healthy	5	50
	Poisoning	5	50
Drill + Triclon	Apparently healthy	8	80
	Poisoning	2	20

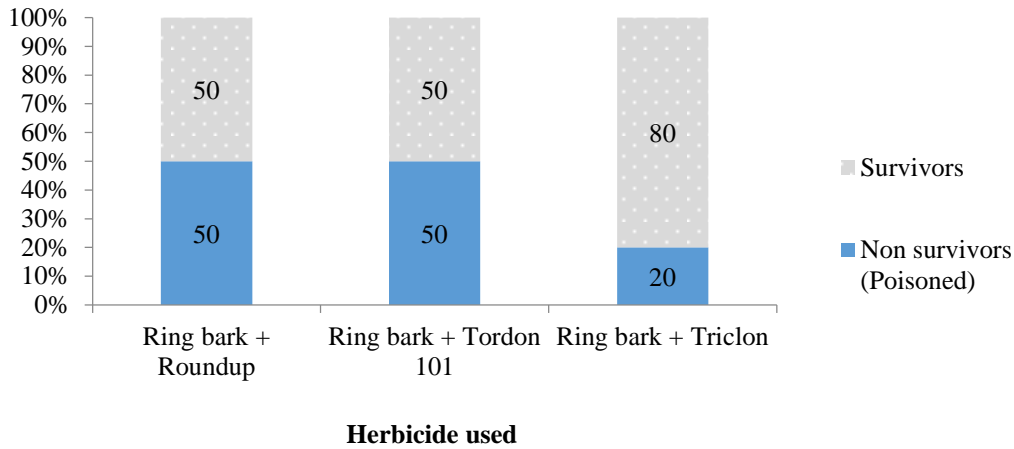


Figure 4. Percentage of survivors and non-survivors for drill application method.

During herbicide application the cut stump technique took less time (Figure 5) compared to ring bark and drill methods, but cut stumps made lots of mess due to felling of trees and did damage some indigenous plants present in the area. Roundup was the most effective herbicide with a mortality rate of 35 (87.5%) individuals compared to Triclon and Tordon 101 herbicide with a mortality rate of 23 (57.5%) and 31 (77.5) respectively (Table 5). In the Ring barking application method, Roundup showed higher mortality rate (15, 100%) compared to Tordon with a mortality rate of 11 (73.3%) individuals. The three herbicides Tordon101, Triclon and Roundup did not affect the plants in the cut stump application method. Triclon was found to be the least effective in ring bark and drill methods.

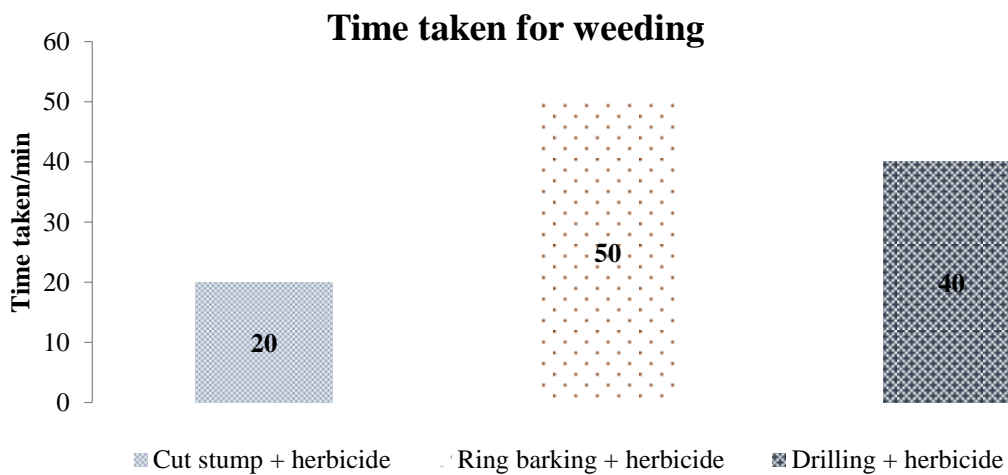


Figure 5. Weeding time for each application method for *T. pallida*.

Table 5. Efficiency of each herbicide for control of *T. pallida* irrespective of application methods.

Herbicide	survivors	Non-survivors
Roundup	12.5%	87.5%
Tordon 101	22.5%	77.5%
Triclon	42.5%	57.5%

Tabebuia pallida has enormously out-competed native species, repressing and even excluding native plant species and thereby brought a change to the ecosystem. These invasive species have indirectly transformed the species composition and structure of the ecosystem by changing the way in which nutrients are cycled through the ecosystem (McNeely et al. 2001). This species occupies most space (vertical and lateral) and has outnumbered native species. It has even caused major economic problems related to their control and eradication. Huge cost would be involved for any herbicide application methods i.e ring barking, drilling and cut stump for large surfaces of restoration. The species produces seed with rigid wings which enable them to fly long distances. These seed wings are balanced and twisted so that the seed spins around as it is carried along by the wind. Seed dispersal has been the most important phase in the regeneration process of the species population. It is through seed dispersal that the population of this invasive species has burst out. The efficiency of each herbicide has been evaluated according to the number of plants that have not survived (poisoned or dead) compared to the number of plants that survived. In commercial plantations, herbicide use in improving plantation tree growth has been well documented (McDonald et al. 1994; George and Brennan, 2002). Over a two-year monitoring period, herbicides use were found to be more cost-effective in controlling weeds compared to other weed control methods (George and Brennan, 2002).

Roundup was found to be the most effective herbicide. Glyphosate the active ingredient proved to provide effective control against the invasive species. Glyphosate being water-soluble was successfully absorbed by the cambium layer. Unlike tordon 101 and triclon its effect was quick and acted upon the whole tree. However, glyphosate is considered to be a high risk herbicide for non-target plants. Glyphosate alone has less toxicity but when mixed with other active ingredients the product become more toxic. Tordon 101 proved to be the next efficient herbicide to be used after Roundup. Tordon 101 contain picloram and 2,4-D as active ingredients. According to observation made, the response of Tordon 101 was quite satisfactory. It can be used as an alternative to roundup. However, it was only after 9 weeks that its effects were observed. The trees treated with Tordon 101 were generally poisoned and only few were dead compared to roundup where the

trees were completely dried out. Tordon 101 can harm other broadleaved plants in the proximity of the treatment area. Triclon did not prove to be effective in the control of the invasive species. The trees responses to triclon were almost negligible. Triclopyr, the active ingredient present in triclon is low in toxicity. According to Tu et al (2001), the salt formulation is soluble in water, and with adequate sunlight it may degrade in several hours. One cause of its low response might be due to the fact that the herbicide degrades when it is in contact with water and sunlight. Trees that were treated with Triclon were half poisoned; that is, only the lower part of the trees was affected. The upper leaves were green and unharmed. This is because the herbicide did not move up the trees completely. It can be due to lower absorption or lower half-life of the herbicide.

Cut-stump method is very effective when large population needs to be eliminated. Cut stump method take less time than ring barking and drilling. It can also be deduced that re-sprouting would take years to occur and even if herbicide would not have been applied the mortality rate would be the same. It is difficult to say which herbicide showed promising results using this method. Therefore, this method could not be compared about its effectiveness between the other two methods. However, changes could be observed after a long period of monitoring due to the fact that the diameter of the tree is high and it would take time for re-sprouting. According to Tu et al. (2001), the cut stump treatment allows for more control on the site where herbicide is applied, and it, has a low possibility of contaminating the environment or affecting non-target species. It also requires only a small amount of herbicide to be effective.

The cut treatment had a negative impact on the growth rate of endemic species since the felling of trees damaged some of the species. A certain level of collateral damage can be accepted in conservation management if the overall effect is above all more positive. The canopy of the trees also contributes to the loss of the species. The larger the canopies the more species are destroyed. Soil erosion can cause major damage when the trees are cut down. These large trees play a major role in maintaining the soil structure together. There is also habitat destruction when the trees are cut. Girdling/Ring barking allowed the cambium layers to be exposed and enabled maximum movement of herbicide within the plant. Girdling is also known as standing tree stem technique. This method is a very cost-effective way to kill very large plants. Less labor and no sophisticated and costly equipment are required. This technique is simple and easily performed. No indigenous species are destroyed since these trees can be left standing and it also provide habitat for beneficial species. However, to assure a more effective kill, the inner bark should be continuously removed in a band of at least one inch wide. A chainsaw could be used to remove the bark to a depth of one to two inches. Girdling alone is generally less dependable, takes longer to be effective, and can actually

stimulate sprouting compared to when herbicides are incorporated into the treatment (Stelzer, 2006).

Drilling technique did not prove to be efficient. Drilling individual stem was more costly since the tree has a high hardwood density. Drilling would have been more effective if the trees were 3 to 4 inches in diameter. One ecological advantage in using drill technique over the cut technique is that habitat structure remains in place. Birds and other animals use weeds as shelter and therefore this technique is less disruptive to them as it leaves most of the structure intact. Cut stump application was found to be the best application method which involved felling the whole plant 10-15cm above ground level using a chainsaw. This procedure readily exposes the cambium layers. The mortality rate in the ring barking method is reasonable. The result is targeted to the elimination of at least 95% for restoration purposes and ring barking method reached this target. However, ring barking can be used in sparsely invaded areas. Moreover, heavy downpour reduces the effect of the herbicide by partial wash out. There is also wastage of herbicide during the application which can affect the soil biota. In the case of drilling either the volume applied is insufficient or the herbicide has not reached all tissues in the affected area. Possibly the drilled holes need to be filled once every week for sufficient absorption to kill the plants.

Costs associated with herbicide application methods have two major components namely chemical cost and labor cost. In order to decrease total treatment costs, one approach is to reduce labor cost by applying less herbicide mixture per tree while the herbicide concentration is increased to maintain effectiveness. Another way to reduce treatment cost is by using more labor-efficient tools. In order to estimate total cost for this study, it is important to define it in terms of number and size of trees to be treated per acre. In this study, herbicide use as a weed control method was investigated so as to assess its effectiveness, cost efficiency and any adverse impact occurring on the native flora. According to Florens and Baider (2005), maintenance weeding over 15 years had cost about US \$ 53 000 per hectare. At Mt Camizard, the total cost of weeding per hectare was estimated to be US \$672 for the cut and herbicide application. Ring barking with herbicide application costs about US\$ 1181 per hectare (Larose 2005). These new techniques are more cost-effective than the current weeding practices. Mechanical weeding which involve the use of chainsaw, rechargeable drill and diesel is more effective than doing manual weeding. Manual control is very tedious and time consuming. It is not practical to use on large scale area of restoration. In terms of labor, manual weeding needs more workers than mechanical control. However, mechanical weeding could have a slightly higher cost compared to manual weeding but this technique is time efficient and death rates of invasive species are higher. Efficacy of the

herbicides does not depend on their cost. For example, the price of 1L roundup is US \$ 10 and the number of non-survivors with the herbicide is 88% while the price of 1L Tordon 101 is US\$ 21 and the percentage of non-survivors was found to be 78%. Cut with herbicide application takes lesser time than ring barking and drilling. The average time taken to ring bark 625m² was about 10 hours per person while that of the cut and drill techniques was lower. From present observations, the ring bark method was a more tedious weeding process with workers more fatigue. There are two important concepts in conservation management of native flora: removal of alien plants and secondly ecological restoration. The best treatment which will be effective in killing a large proportion of the alien species needs to be chosen. Our study suggests the best methodology to control *T. pallida* to be cut stump followed by Roundup.

Conclusion

T. pallida represents a serious threat to the forest ecosystems of Mauritius. There is thus a need to find appropriate actions to manage this weed. The present study investigates the effectiveness of different herbicides and application techniques for the control of *T. pallida*. The effects of the Roundup were quick and were observed on the whole tree making it the most suitable herbicide. Triclon 101 also proved to be effective and is thus a good alternative to Roundup which has the disadvantage of being of high risk to non-target trees. Tordon had negligible effects. Cut stump was the best application method, killing all the trees treated independent of the herbicide applied. Ring Barking is also an efficient method; it is not too costly but takes a longer period of time to be effective. Drilling was the least efficient. A combination of chemical and mechanical methods is effective in the control of *T. pallida*.

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Conflicts of Interest

Authors declare no conflicts of interest for this study.

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